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Application of magnetic force microscopy to study the epitaxial ferro- and antiferromagnetic microstructures

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In the last few decades, spintronics has become to one of the promising areas of electronics, in which the electron spin is essentially exploited. Because of the use of ferro- and antiferromagnets in spintronics, the study of their magnetic states that depends on the external magnetic field and the applied spin-polarized current is of great interest. The most common method for such studies is magnetic force microscopy (MFM), having advantages in ease of use and availability. However, the magnetic contrast obtained by this method is not always easy to interpret and unambiguously determine the magnetic structure - the spatial distribution of magnetization. For this interpretation, the simulation within the framework of the Brown's approach, called micromagnetism, is actively used in combination with other experimental methods.

The magnetic states of micro- and nanostructures fabricated from ferro- and antiferromagnetic films depend strongly on the quality of their crystal structure. For the purity of the experiments, it is worth to investigate epitaxial micro - and nanostructures, which guarantees implementation of spatially ordered and regular magnetic states. Examples of studies of such structures by magnetic force microscopy in combination with micromagnetic calculations and other magnetically sensitive methods are presented below.

Studies by the MFM and micromagnetic calculations of iron epitaxial microstructures revealed a dependence of their magnetic states versus both the type of the substrate, microstructure's dimensions and lateral orientation against the substrate. The different types of regular magnetic states were experimentally observed. It was shown that the iron films on the a-plane sapphire substrate possess one easy in-plane magnetization axis, made 35° angle against the base cut of the substrate, while for the r- plane sapphire substrate – there are two easy axes, parallel and perpendicular to the base cut. This corresponds to the epitaxial growth of iron films of (011) and (001) orientations, respectively. Using the same approach, the magnetic states of the epitaxial microstructures of the Heusler alloys Co_2FeAl and Fe_2CoAl that grown on the same substrates were also investigated. New results have been found, which can be explained by the deviation of the lattice symmetry of the grown films from the cubic symmetry.

Carried experiments have been also accomplished by magnetoresistive measurements, the results of which allow finding the coercive fields and the type of the magnetic anisotropy in epitaxial films consisting of ferro- and antiferromagnetic metals and their alloys. These measurements also made it possible to study the interlayer exchange interaction in epitaxial ferromagnetic – antiferromagnetic (FM/AFM) structures, in which the application of annealing in a magnetic field above the Neel temperature forms a unidirectional exchange anisotropy. This anisotropy is manifested in the magnetic structure of the ferromagnetic layer, which can be studied by MFM. Micromagnetic calculations have predicted the influence of the roughness of the FM/AFM interface on this interaction.